Modeling and Optimization of Plasma Arc Cutting Process Parameters for M.S (IS 2062)

Industry Name:
Trimurti Industries,Odhav,Kathvada GIDC, Ahmedabad

GROUP NO-15

Guided by:
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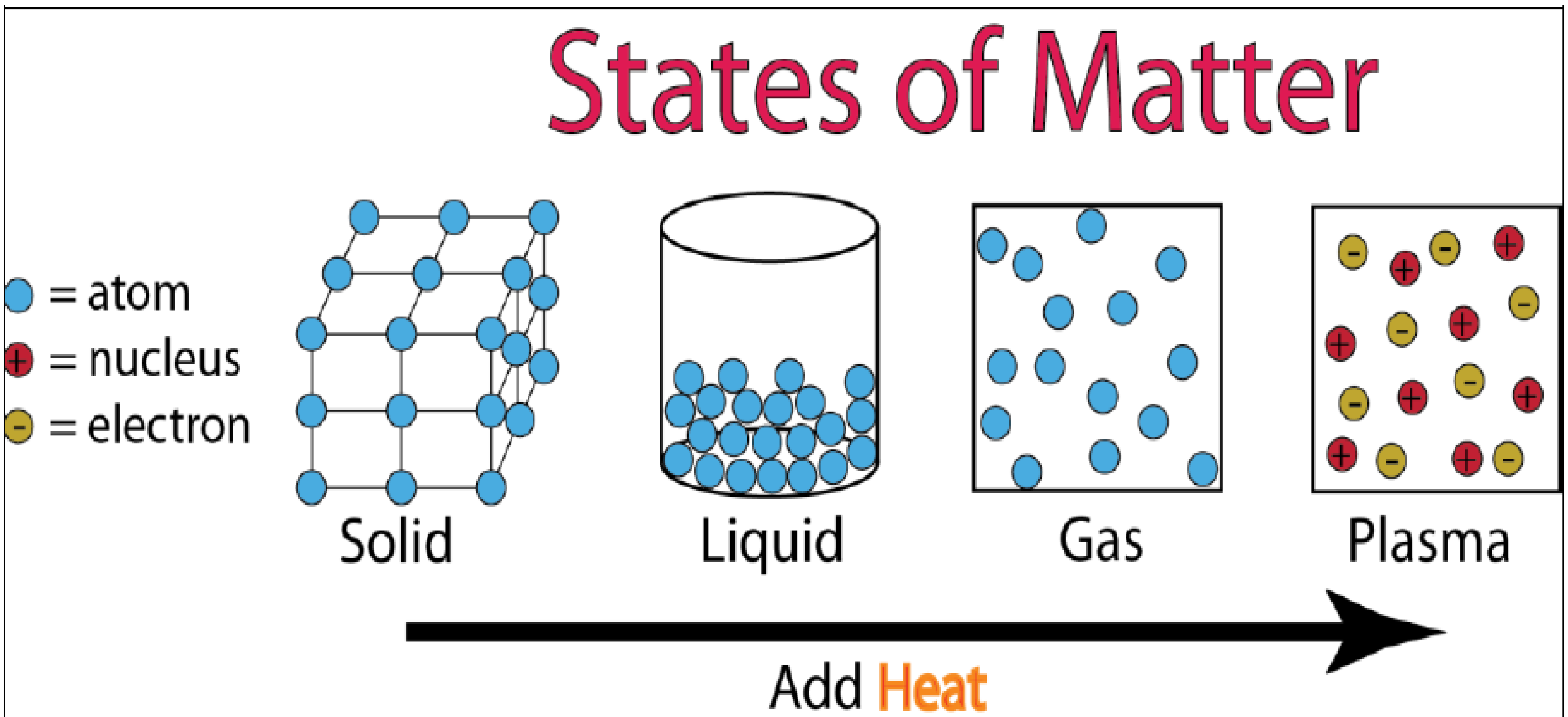
- Problem formulation
- Objective
- Literature review
- Methodology
- DOE and Result
- S/N ratio (Continue…)
- Regression analysis
- ANOVA analysis
- Conformation test & Conclusion
- Scope Of Work
- References

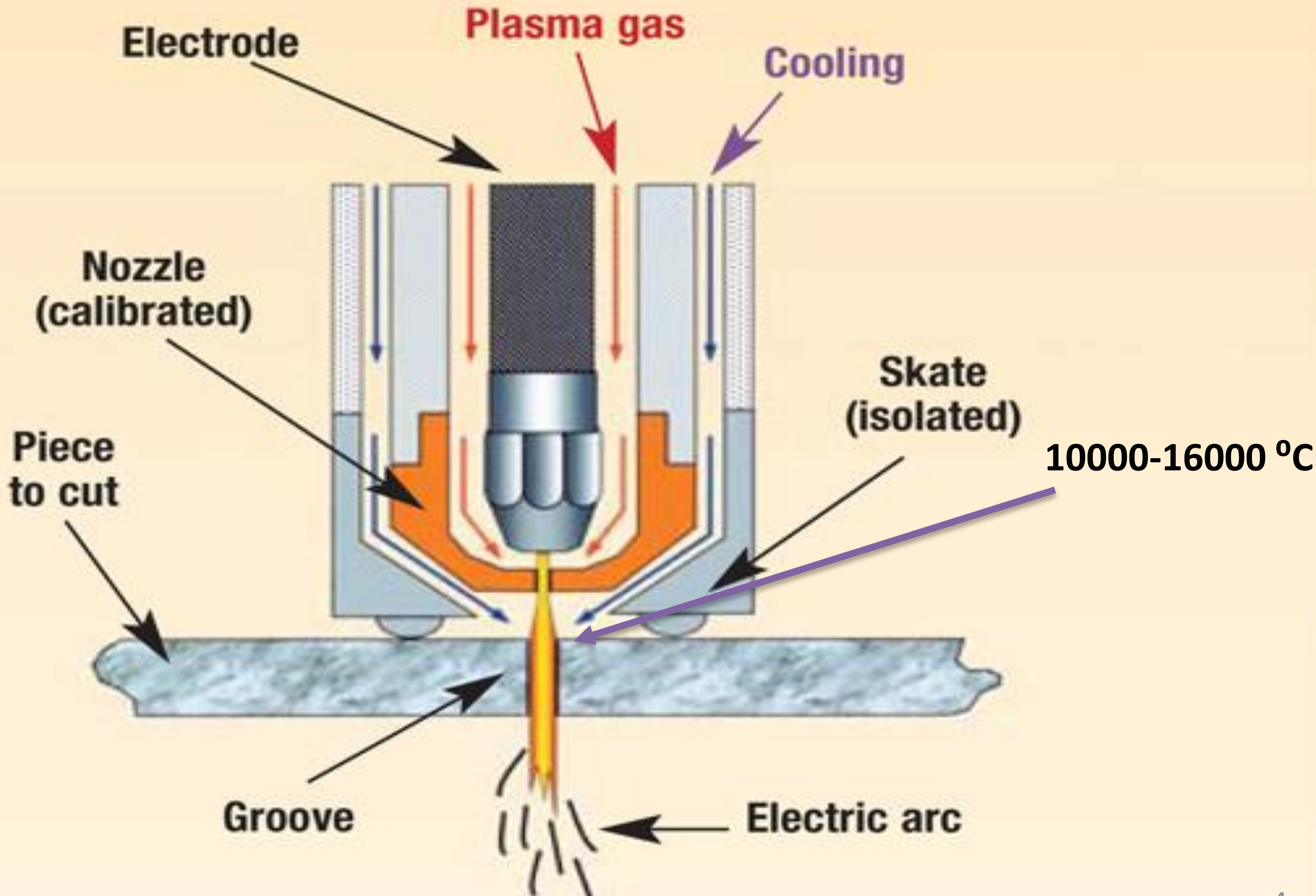
Introduction

Definition:- .

A **plasma** is a hot ionized gas consisting of approximately equal numbers of positively charged ions and negatively charged electrons. The characteristics of plasmas are significantly different from those of ordinary neutral gases so that plasmas are considered a distinct "fourth **state** of matter."



PLASMA CUTTING PROCESS



Gases used in Plasma

- Gases that are used to create the plasma arc.

  Examples of primary gases are nitrogen, argon, hydrogen or mixture of them and secondary gas is air.

- Input Parameters

  Air Pressure (N/Cm^2)

  Current flow rate (A)

  Cutting speed (mm/min)

  Arc gap (mm)

- Output Parameters

  Material Removal Rate (gm/min)

  Surface Roughness (µm)

  Kerf Width (mm)

Technical Specification

HyPerformance Plasma HPR130 Machine

Parameter	Range
Power voltage (v)	Single phase 230v ±15% Three phase 400v ±15%
No load voltage (v)	311 VDC
Rated output current (A)	30-130
Rated output voltage (v)	50-150 VDC
Duty cycle	100%
Gas Pressure(Plasma And Shield) (N/cm^2)	30-80
Size (mm)	1079.5*566.4*967.7

Problem Formulation

Plasma arc cutting can be characterized in terms of two different speeds.

- At higher cutting speeds , the plasma jet does not cut through metal plate.
- At lower speeds , the molten metal from the kerf sticks to the bottom of the plate. so, we have to optimize proper parameters (Air pressure , current flow rate, cutting speed, arc gap) for plasma arc cutting.

Objective

This project was developed to study about the plasma arc cutting parameter in smooth cutting using straight polarity process.The main purposes of this project are listed below:

- To study about the influence of Plasma Arc Cutting Parameters on M.S (IS 2062).
- To design a series of experiment using the help of Design of Experiments (DOE) layout in order to study about Plasma Arc Cutting (PAC).
- To study about the best combination of solution for maximizing the Material Removal Rate (MRR) and for minimizing the Surface Roughness (µm) and measure kerf width with Taguchi Method.
- Analyse process performance data for various parameters using ANOVA and Regression
- find optimum combination of process parameters with suitable weights assigned to each quality parameter of the cut.

Literature Review

Research Paper Name	**Investigation Analysis of Plasma arc cutting Parameters on the Unevenness surface of Hardox-400 material**
Year	**2013**
Author	**Subbarao Chamarthi, N.Sinivasa Reddy, Manoj Kumar Elipey, D.V. Ramana Reddy**
Material	Hardox-400 material
Input parameters	cutting speed, plasma gas and arc voltage
Output parameters	Surface finish,material removal rate
Conclusion	Cutting speed increase or decrease inversely proportional thickness of plate. As recorded optimum value of 70L/Hr plasma flow rate, 125 V voltage and 2100 mm/min cutting speed.

Research Paper Name	**Experimental Investigation of the Plasma Arc Cutting Process**
Year	**2012**
Author	**K. Salonitis, S. Vatousianos**
Input parameters	Cutting speed,cutting current,cutting height, plasma gas pressure
Output parameters	Surface roughness,heat affected zone, conicity of the cut geometry
Material	S235 mild steel sheets
Conclusion	Using design of experiments and analysis of variance, it was found that the surface roughness and the conicity are mainly affected by the cutting height, whereas the heat affected zone is mainly influenced by the cutting current.

Research Paper Name	**A Review of Parametric Optimization of Plasma arc cutting process of SS 310**
Year	**2015**
Author	**Sunil I. Thakkar, Prof. V. N. Patni**
Input parameters	Cutting speed, cutting current, standoff distance, cutting voltage, plasma gas pressure and gas flow rate
Output parameters	surface roughness, material removal rate and kerf width
Material	ss 310
Conclusion	The oxygen is used as the cutting gas the oxidation reaction will occur and result in higher feed rates and unevenness and kerf width of better quality were achieved. For the thin plate of work piece material cutting current and cutting voltage should be decrease and cutting speed should be increase for better surface roughness.

Research Paper Name	**Surface Roughness and MRR Effect on Manual Plasma Arc Cutting Machining**
Year	**2012**
Author	**R. Bhuvenesh, M.H. Norizaman, M.S. Abdul Manan**
Input parameters	1. Air pressure [bar]. 2. Cutting current [A]. 3. Cutting speed [mm/min]. 4. Arc gap [mm].
Output parameters	Material removal rate,surface roughness
Material	AISI 1017 mild steel
Conclusion	1) The SR values are inversely proportional to the MRR values. 2) The dimensions of the dross determine the quality of plasma arc cutting in terms of surface roughness

Research Paper Name	**Real-Time Control of the Plasma Arc Cutting Process by Using Intensity Measurements of Ejected Plasma**
Year	**1991**
Author	**K. - M . YUN AND S. -J. NA**
Input parameters	Plasma Arc Cutting,Real-Time Control,Ejected Plasma Intensity Measures,Plasma Cut Quality,Plasma Intensity, Cut Thickness
Output parameters	Cut quality,kerf width
Material	Stainless steel
Conclusion	This investigation has shown that thecut quality can be improved in plasma arc cutting of plates with varying thicknesses by applying a real-time control of the cutting speed.

Research Paper Name	**Optimization of Process Parameters in Plasma Arc Cutting of EN 31 Seell Based on MRR and Multiple Roughness Characteristics Using Grey Relational Analysis**
Year	**2014**
Author	**Milan Kumar Das,Kaushik Kumar,Tapan Kr. Barmar,Prasanta Sahoo**
Material	EN 31 Steel
Input parameters	gas pressure, arc current,torch height
Output parameters	Surface roughness,material removal rate
Conclusion	Based on ANOVA ,the highly effected parameter is gas pressure, whereas arc current and torch height are less effective factors within the specific test range.

Research Paper Name	**Optimization of MRR and Surface Roughness in PAC of EN 31 Steel Using Weighted Principal Component Analysis**
Year	**2014**
Author	**Milan Kumar Das,Kaushik Kumar,Tapan Kr. Barmar,Prasanta Sahoo**
Input parameters	gas pressure, arc current,torch height
Output parameters	Surface roughness,material removal rate
Material	EN 31 Steel
Conclusion	From ANOVA, it is seen that the gas pressure is the most influencing parameter that significantly affects MRR and surface roughness characteristics followed by arc current. Among the interactions, interaction between gas pressure (A) and arc current (B) has the Maximum contribution on responses

Research Paper Name	**Experimental study of the features of the kerf generated by a 200A high tolerance plasma arc cutting system**
Year	**2007**
Author	***R. Bini, B.M. Colosimo, A.E. Kutlu, M. Monno***
Material	Steel
Input parameters	gases flow rates and composition
Output parameters	high productivity with good cutting quality.
Conclusion	It was found out that the arc voltage is the main parameter and it influences all the aspects related with the cut quality. it was shown that very good quality can be achieved for all the sides by varying the cutting speed and the arc voltage only.

Research Paper Name	**Plasma surface hardening of ASSAB 760 steel specimens with taguchi optimization of the processing parameters.**
Year	**2001**
Author	**L.J. Yang**
Material	ASSAB 760 Steel
Input parameters	Arc current,gas flow rate,torch traversing speed
Output parameters	Hardened depth
Conclusion	The hardened depth obtained from 0.08 to 0.37 mm, with an average value of 0.195 mm.

Research Paper Name	**Parameters Optimization of Plasma Hardening Process Using Genetic Algorithm and Neural Network**
Year	**2011**
Author	**LIU Gu, WANG Liu-ying , CHEN Gui-ming , HUA Shao-chun**
Material	AISI 1045 carbon steel
Input parameters	Plasma arc current,gas floe rate
Output parameters	Optimum hardened depth, surface roughness
Conclusion	Through multi-optimizations, the optimum comprehensive performances of the hardened layer are obtained: hardened depth is 0.39 mm, surface roughness is 2.44 μm

Methodology

Selection and study about related work

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Parameter selection, their levels, Responses

↓

Taguchi Design of experiment

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Experimentation and measurement

↓

Regression Analysis (Continue..)

↓

ANOVA analysis

↓

Conformation test & Optimization

↓

Conclusion

↓

End

Chemical Composition Of M.S (IS 2062)

Elements	Wt.%
Carbon	0.130
Silicon	0.030
Sulphur	0.005
Phosphorus	0.010
Manganese	0.890
Nickel	0.022
Chromium	0.033
Moly	0.004
Vanadium	0.035
Copper	0.032
CEV	0.296

Application of M.S (IS 2062)

- Automobile
- Boiler and Pressure Vessels
- Heavy Fabrication
- Ship Building
- Railways
- Oil and Petrochemicals
- Marine containers

Design of Experiment

Doe helps in:
To find out which factors have effects on the response and the direction of the influence (i.e. Whether the increase of a factor will increase or decrease the response?) means importance of factor.

Taguchi Design

- *Dr. Genichi Taguchi is father of the "Taguchi Method" and "Robust Engineering"*
- *He is an electrical engineer.*

The Taguchi Design Process

- Taguchi Design provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions.
- The Taguchi method is a standardized approach for determining the best combination of inputs to produce a product or service.
- We have take L16 Taguchi Orthogonal array for design of experiments.
- Since the numbers of factors are four with four levels therefore most suitable taguchi orthogonal array for the experiments was L16 array.

Parameter and Level Selection

Parameters	Symbol	Level 1	Level 2	Level 3	Level 4
Air Pressure(N/cm^2)	A	30	40	45	55
Current flow rate(A)	B	50	70	90	110
Cutting speed (mm/min)	C	550	650	750	850
Arc gap (mm)	D	3	4	5	5.5

Experimental Result

EX. NO	Air Pressure (N/cm²)	Current Flow (Amp.)	Cutting Speed (mm/min)	Arc Gap(mm)	SR (µm)	MRR (gm/min)	KW (mm)
1	30	50	550	3	2.89	132.526	3.48
2	30	70	650	4	2.55	119.402	4.01
3	30	90	750	5	2.33	105.461	3.25
4	30	110	850	5.5	2.17	199.095	3.31
5	40	50	650	5	2.72	103.004	2.50
6	40	70	550	5.5	2.47	125.412	2.54
7	40	90	850	3	2.27	112.994	3.26
8	40	110	750	4	3.08	110.403	3.23
9	45	50	750	5.5	2.26	118.143	2.93
10	45	70	850	5	1.89	138.309	3.07
11	45	90	550	4	3.49	135.593	3.14
12	45	110	650	3	3.18	129.292	3.09
13	55	50	850	4	1.84	104.683	2.94
14	55	70	750	3	2.33	117.839	3.09
15	55	90	650	5.5	2.46	123.188	3.25
16	55	110	550	5	3.23	131.687	3.13

MRR

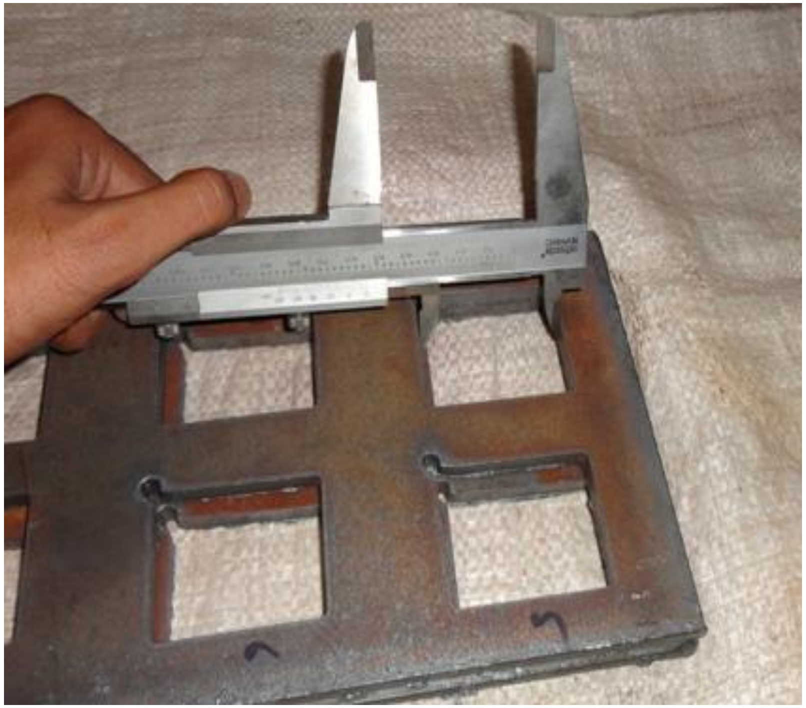
- The material removal rate (MRR) can be defined as the volume of material removed divided by the machining time. Material Removal Rate (MRR) is defined by:
- **MRR =** $\frac{WRW}{T}$ **[gm/min]**
- Where,
- WRW: Work piece Removal Weight (gm)
- T: cutting time (min)
- WRW is the weight different between before and after work piece cutting. The volume different can be calculated when information regarding material density available. The relation between WRW and WRV is given as follow:
- **WRW =WRV*ρ**
- Where,
- ρ : Work piece density (g/ mm3)

Surface Roughness

- In this experiment, surface roughness is measured using surface tester Mitutoyo SJ-201P.

Kerf Width

- The kerf width can be measured using measuring scale, vernier caliper and using the image tool analyser software. But, in this experiment, kerf width is measures using the vernier caliper.

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S/N Ratio Graph

- Once the experimental design has been determined and the trials have been carried out, the measured performance characteristic from each trial can be used to analyse the relative effect of the different parameters. The product/process/system design phase involves deciding the best values/levels for the control factors. The signal to noise (S/N) ratio is an ideal metric for that purpose.
- **Larger is Better :** **$S/N = -10*\log(\sum(1/Y^2)/n)$**
- **Smaller is Better:** **$S/N = -10*\log(\sum(Y^2)/n)$**
- Where
- Y = responses for the given factor level combination
- n = number of responses in the factor level combination.

- **Nominal is best:**
  S/N= -10*log(square of means/Variance)

S/N Ratio for S.R

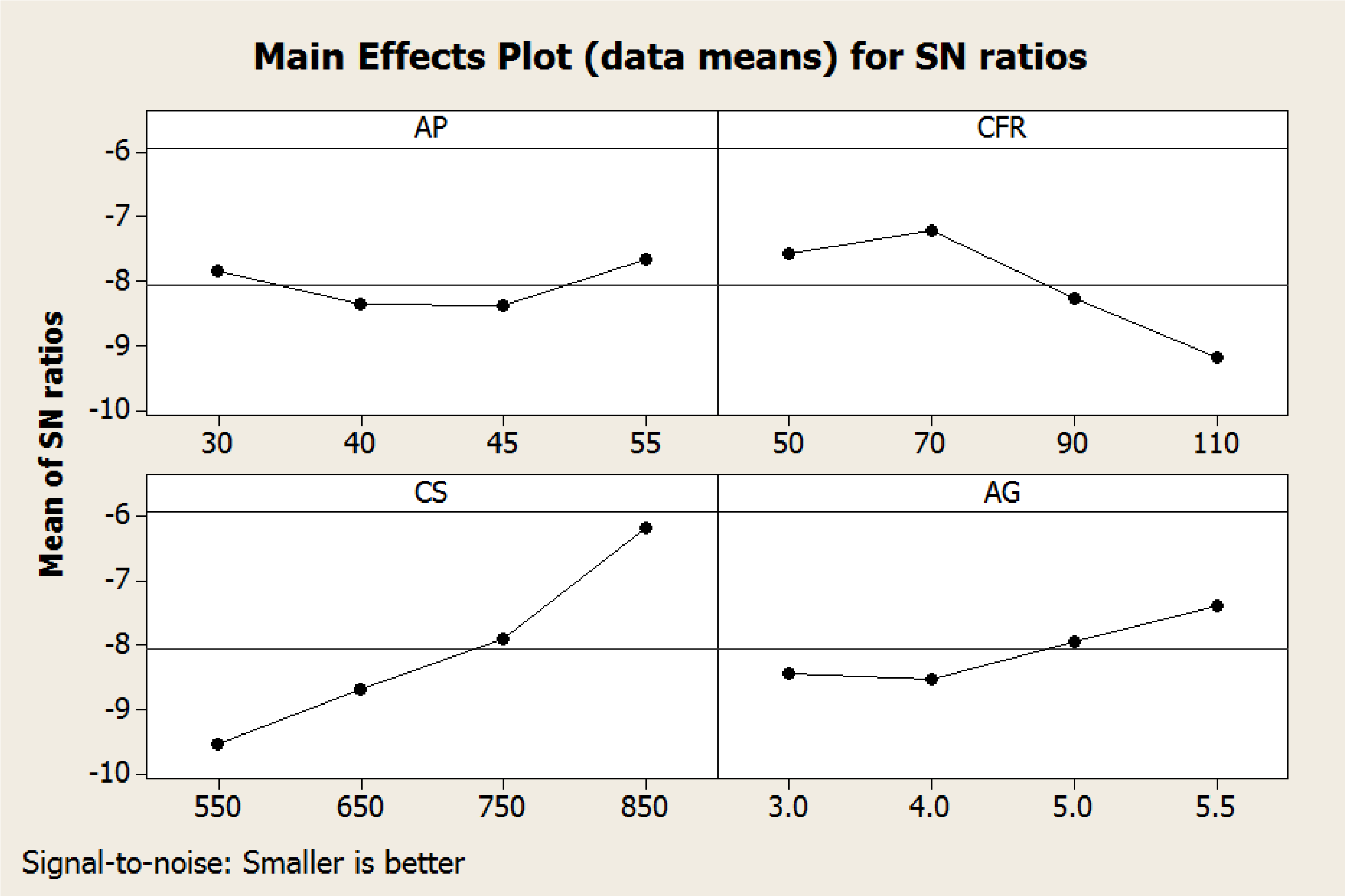

Fig. shows that the lower SR will meet at air pressure 45 N/cm^2, current flow rate 110 A, cutting speed 550 mm/min and arc gap 4 mm. The graph generate by the use of MINITAB statistical software for SR.

It has been conclude that the optimum combination of each process parameter for lower SR is meeting at low cutting speed [C1], medium air pressure [A3], lower current flow rate [B4] and hmedium arc gap [D2].

S/N Ratio for M.R.R

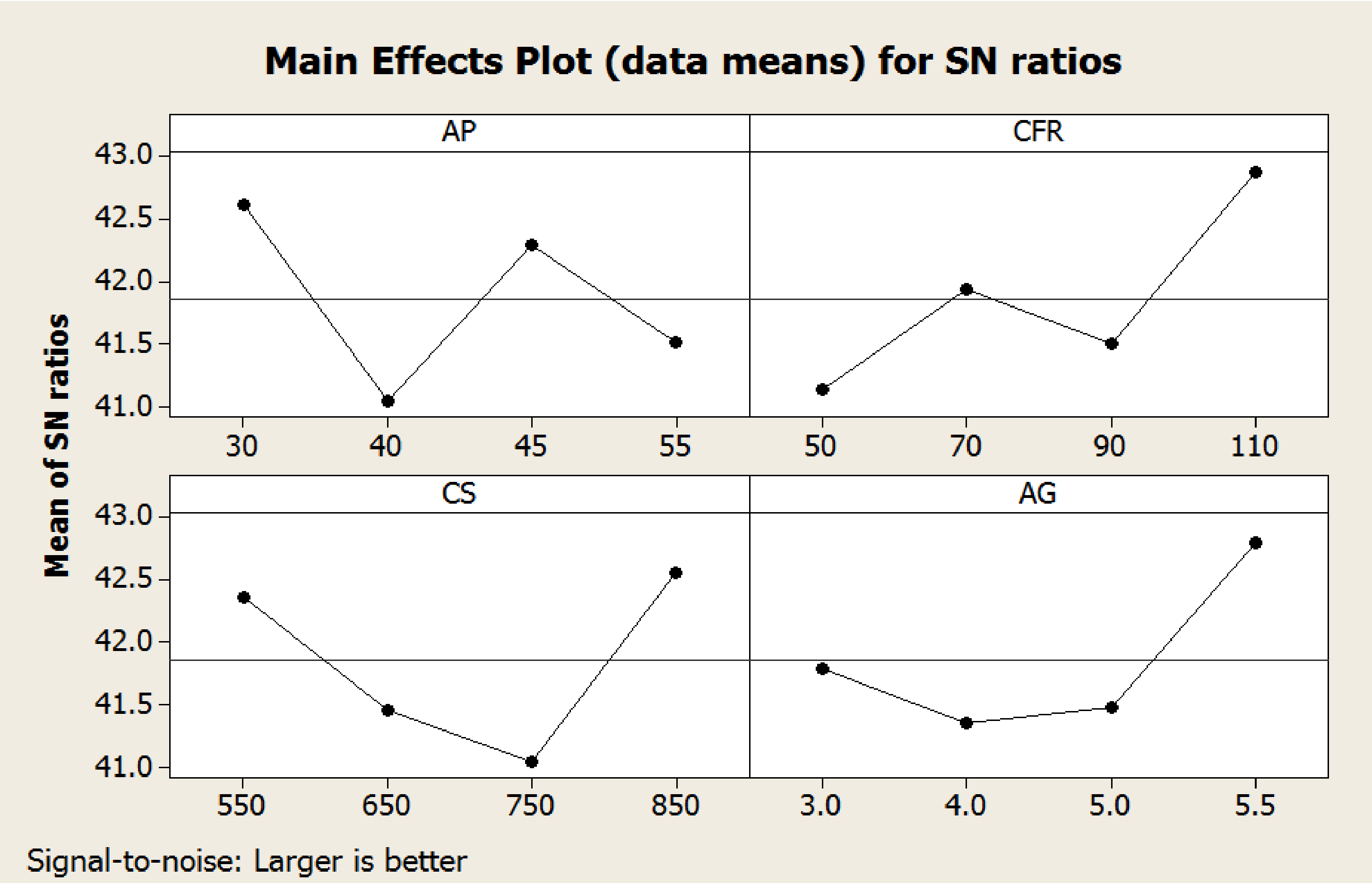

Fig. shows that the higher MRR will meet at air pressure 30 N/cm^2, current flow rate 110 A, cutting speed 850 mm/min and arc gap 5.5 mm. The graph generate by the use of MINITAB statistical software for MRR.

It has been conclude that the optimum combination of each process parameter for higher MRR is meeting at high cutting speed [C4], low air pressure [A1], high current flow rate [B4] and high arc gap [D4].

S/N Ratio for K.W

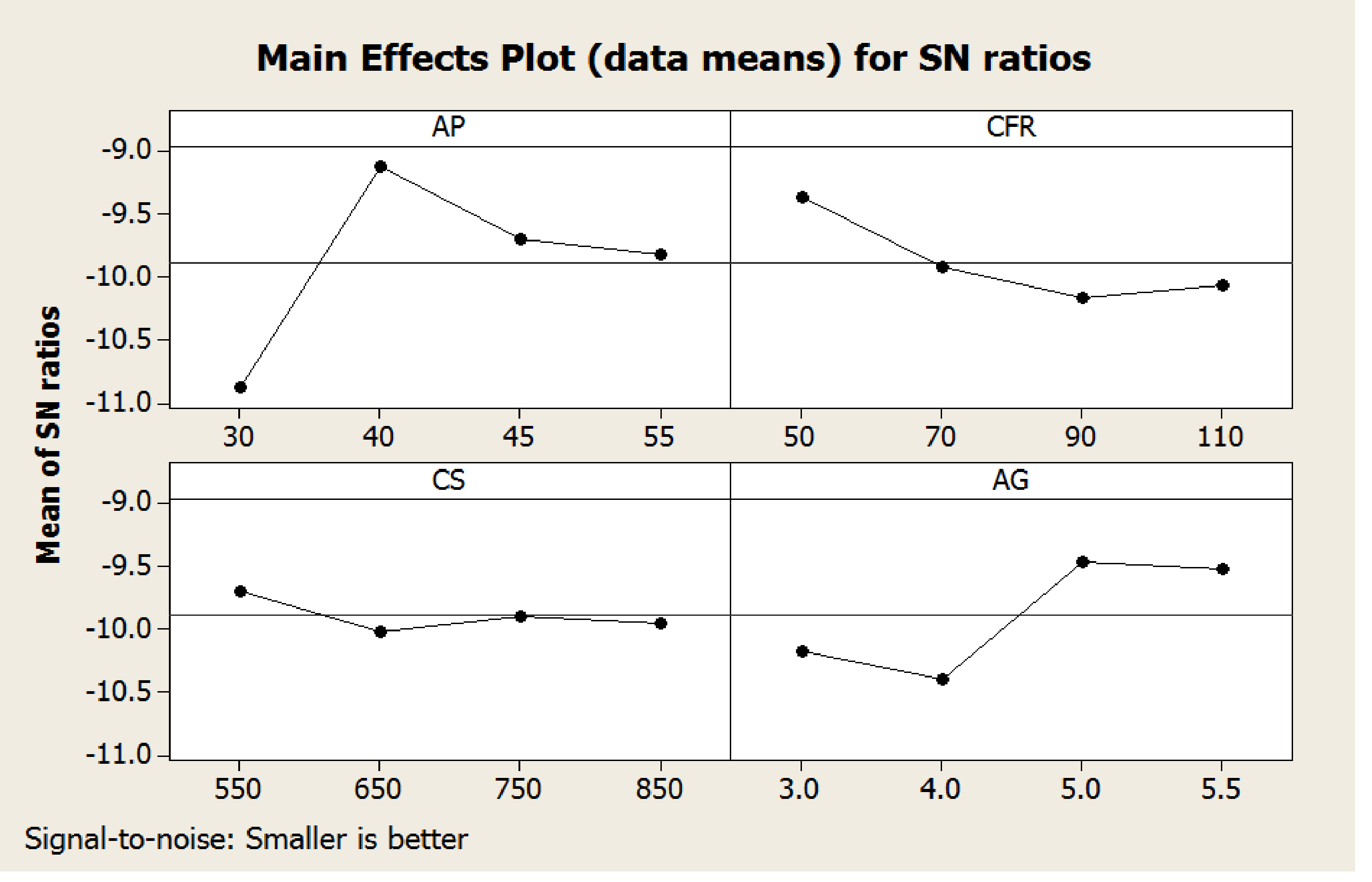

Fig. shows that the lower KW will meet at air pressure 30 N/cm^2, current flow rate 90 A, cutting speed 650 mm/min and arc gap 4 mm. The graph generate by the use of MINITAB statistical software for KW.

It has been conclude that the optimum combination of each process parameter for lower KW is meeting at medium cutting speed [C2], lower air pressure [A1], medium current flow rate [B3] and medium arc gap [D2]

Regression Model & Analysis

Regression analysis is often used to:

(1)Determine how the response variable changes as particular predictor variable changes.

(2)Predict the value of the response variable for any value of the predictor variable, or combination of values of the predictor variables.

Response= constant+ coefficient (predictor)+ ….+coefficient (predictor)

OR

$$Y= b_1+b_1x_1+b_2x_2+ \ldots+b_kx_k$$

Where,

- Response(Y) is the value of the response.
- Constant(b_0) is the value of the response variable, when predictor values is zero.The constant is also called the intercept because it determines where the regression line intercepts (meets) the Y-axis.
- Predictor (X) is the value of the predictor variable.
- Regression analysis and ANOVA is also done by MINITAB software.

Regression Equation For S.R

Predictor	T	P
Constant	7.87	0.000
Air Pressure	-0.03	0.973
Cutting Flow Rate	3.33	0.007
Cutting Speed	-5.87	0.000
Arc Gap	-2.05	0.065
S=0.240573	**R-Sq=81.91%**	**R-Sq(Adj.)=75.3%**

The regression equation is

SR = 4.64 - 0.00023 AP + 0.00895 CFR - 0.00316 CS - 0.128 AG

From regression Result ,It is observed that air pressure and arc gap are not significant parameter for S.R because its value is greater than 0.05 while cuuting flow rate and cutting speed are significant parameter for S.R

Regression Equation for M.R.R

Predictor	T	P
Constant	1.56	0.147
Air Pressure	-1.02	0.331
Cutting Flow Rate	1.57	0.144
Cutting Speed	0.34	0.744
Arc Gap	0.96	0.357
S=0.222013	**R-Sq=79.3%**	**R-Sq(Adj.)=71.5%**

The regression equation is

MRR = 84.9 - 0.627 AP + 0.391 CFR + 0.0166 CS + 5.55 AG

From regression result, it is observed that the all parameter are not significant for MRR, because the value of p-value for all the input parameter is greater than 0.05 p value. So, it is not significant parameter for MRR.

Regression Equation for K.W

Predictor	T	P
Constant	4.76	0.001
Air Pressure	-1.56	0.147
Cutting Flow Rate	0.98	0.348
Cutting Speed	0.17	0.865
Arc Gap	-1.37	0.197
S=0.333299	**R-Sq=81.6%**	**R-Sq(Adj.)=73.2%**

The regression equation is

KW = 3.89 - 0.0144 AP + 0.00365 CFR + 0.000130 CS - 0.119 AG

From regression result, it is observed that the all parameter are not significant for KW, because the value of p-value for all the input parameter is greater than 0.05 p value. So, it is not significant parameter for KW.

Analysis Of Variance (ANOVA)

- Analysis of variance (ANOVA) is a statistical model which can be used for find out effect of independent parameter on single dependent parameter and also it can be use full to find out the significant machining parameters and the percentage contribution of each parameter.
- ANOVA is used to check the sufficiency of the second order model which includes test for significance of regression model, model coefficients and test for lack of fit.
- The ANOVA analysis for MRR and Ra are illustrated in the tables where columns describe the degree of freedom (DF),the sequential sum of squares (Seq SS), adjusted sum of squares (Adj SS), adjusted mean squares (Adj MS), F- values (F) and probability of certainty (P).
- The sequential sum of squares (Seq SS) is the added sum of squares given that the prior terms are in the model, which depends on the model order.
- A low **P- value ($\leq$0.05)** indicates statistical significance for the source on the corresponding response ($\alpha = 0.05$) or 95% confidence level.
- We take anova analysis with regression analysis.

ANOVA for S.R

Source	DF	SS	MS	F	P
Regression	4	2.88147	0.72037	10.45	0.001
Residual error	11	0.63663	0.05788		
Total	15	3.51810			

From anova result , the p value of regression is less than 0.05 so we can say that input parameters are significant parameter for surface roughness.

ANOVA for M.R.R

Source	DF	SS	MS	F	P
Regression	4	2242.9	560.7	7.14	0.0342
Residual error	11	5421.9	492.9		
Total	15	7664.8			

From anova result,the p value of regression is less than 0.05 so we can say that input prameters are significant parameter for material removal rate.

ANOVA for K.W

Source	DF	SS	MS	F	P
Regression	4	0.5898	0.1475	8.33	0.029
Residual error	11	1.2220	0.1111		
Total	15	1.8118			

From anova result, the p value of regression is less than 0.05 so we can say that input parametrs are significant parameter for kerf width

Conformation test

•The confirmation test is the final step of this experimentation. The purpose of conformation test is to validate the conclusion during the analysis phase. In addition, the conformation test needs to be carried out in order to ensure that the theoretical predicted model for optimum results using the software is accepted and in order to verify adequacy of the models that are developed.

•In Confirmation Test Once the optimal combination of process parameters and their levels was obtained, the final step was to verify the estimated result against experimental value.

•**Surface Roughness (S.R)**

we conduct conformation test and calculate predicted error which is 3.72% so from predicted error the optimum combination parameters are find out which are match with Experiment no-11 in which Air pressure 45 N/cm^2, Current flow rate 90 A, Cutting speed 550 mm/min and Arc gap 4 mm.

- **Material Removal Rate(M.R.R)**

  we conduct conformation test and calculate predicted error which is 11.14% so from predicted error the optimum combination parameters are find out which are match with Experiment no-10 in which Air pressure 45 N/cm^2, Current flow rate 70 A, Cutting speed 850 mm/min and Arc gap 5 mm.

- **Kerf Width (K.W)**

  we conduct conformation test and calculate predicted error which is 2.41% so from predicted error the optimum combination parameters are find out which are match with Experiment no-4 in which Air pressure 30 N/cm^2, Current flow rate 110 A, Cutting speed 850 mm/min and Arc gap 5.5 mm.

Work Plan

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March	April
Define of problem									
DOE									
Analysis									
Optimization & Modeling									
Conformation & conclusions									

Conclusion

- From Regression analysis we can say that p –value of cutting flow rate and cutting speed is less than 0.05 so they are most influencing parameters for surface roughness(S.R) , In Material removal rate(M.R.R) and kerf width(K.W) p-value of input parameters is greater than 0.05 so the input parameters are not influencing the M.R.R and K.W.

The optimum levels of parameter for **minimizing SR** are A_3, B_3, C_1, D_2 i.e.

Air pressure:- 45N/cm^2 Cutting speed:- 550mm/min

Current flow rate:- 90A Arc gap:- 4mm

The optimum levels of parameter for **maximizing MRR** are A_3, B_2, C_4, D_3 i.e.

Air pressure:45 N/cm^2 Cutting speed:- 850mm/min

Current flow rate:- 70A Arc gap:- 5mm

The optimum levels of parameter for **minimizing KW** are A_1, B_4, C_4, D_4 i.e.

Air pressure:- 30N/cm^2

Cutting speed:- 850mm/min

Current flow rate:-110A

Arc gap:- 5.5 mm

Scope of work

Based on conclusion and result,this project had archive it main objective but an improvement still can done to improve more on the Metal Removal Rate (MRR) and Surface Roughness (Ra) and kerf width(K.W)

Based on this work many improvements can be made and the scope can also be widened. Following are suggestion for future work:

- Using Plasma Arc Cutting system, add the parameter such as Voltage, Bevel angle, cutting gas pressure, material dimension, and change advance material such as brass, bronze, harder material like chromium base (H11, H13 etc), hardox series material then compare the result obtained.
- Using other methodology in the same material of study to compare the results obtained such as Response Surface Methodology (RSM), Artificial Neural Network (ANN), and Genetic Algorithm etc.
- No interaction is considered, so we can consider interaction by applying L27 or L32 with 3-level design this will improve optimum condition as compare to L16 considered in this work.
- Also side clearance and thermal effect on material and work piece like Heat Affected Zone (HAZ) can also be considered to study the effect on properties of work piece.

Test Report Of M.S (IS 2062)

DIVINE METALLURGICAL SERVICES PVT. LTD.

TESTING HOUSE OF METALS & ALLOYS
NABL ACCREDITED LABORATORY

Plot no.14, Gopal Industrial Estate, Opp. Vallabhnagar, Odhav, AHMEDABAD-382 415.
Phone : 079 - 2289 1013 Tele/Fax : 079 - 2289 2804 Mobile : 922 722 0993
Email : divinelab_nhp@rediffmail.com, divinelab_nhp@yahoo.com

CERT No. (T-0435)

Test Report

Name & Address of Customer
M/s. Trimurti Industries
25,Tribhuvan Estate,Kathwada GIDC,Odhav,Ahmedabad

Test Report No. S3033
Date : 25/01/2016

Description :	Square Plate
Nature of Sample :	SOLID
Date of Receipt of Sample :	23/01/2016
Test method Used :	ASTM E - 415 - 2008(SPECTRO)
Specification :	IS 2062 Gr. E250BR

Identification : NIL

TEST RESULT

ELEMENTS	PERCENTAGE (%)	Min	Max
CARBON	0.130		0.220
SILICON	0.030		0.400
SULPHUR	0.005		0.045
PHOSPHORUS	0.010		0.045
MANGANESE	0.890		1.500
NICKEL	0.022		
CHROMIUM	0.033		
MOLY	0.004		
VANADIUM	0.035		
COPPER	0.032		
CEV	0.296		0.410

N. B. : -

Remarks : Above Composition/Elements
CONFORM IS 2062 Gr. E250BR

Approved by
MD. / Lab Incharge
(N.H.P. / S.K.G.)

P.T.O.

Format No.: F-16/1

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